NASA Contractor Report 172164

FABRICATION OF SLENDER STRUTS FOR DEPLOYABLE ANTENNAS

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LOCKHEED MISSILES & SPACE COMPANY, INC.
SUNNYVALE, CALIFORNIA 94086

TASK ASSIGNMENT NO. 24
CONTRACT NAS 1-14887
APRIL 1983

National Aeronautics and
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INTRODUCTION

Large diameter aperture antennas have been identified by government and industry studies as a requirement for radiometer and communication missions for the 1990 time frame.

The inherent stiffness associated with tetrahedral truss structures makes them particularly well suited for this application. The work described in this report deals with the manufacturing development of slender struts required for the efficient stowage of such deployable trusses in the Orbiter cargo bay. A number of features are included in both design and the manufacturing process. The strut design includes an overwrap of aluminum foil which significantly improves the thermal conductivity, and has the potential to act as a vapor barrier if necessary, and provides a thermal control surface.

A number of elements have been introduced into the manufacturing process which reduces the labor intensive aspects of fabricating these elements. Included among these elements is the use of a vertical winding machine, teflon mandrel, dry fiber placement, aluminum foil winding off of canted spools, and a pre-wound creeled fiber array.

DESCRIPTION OF STRUTS

Long slender tubular struts approximately 5-m long and 12.7-mm in diam have been identified by the NASA Langley Research Center as the elements required for efficient stowage and deployment of large truss supported antennas. Although strut requirements have not been fully defined at this time, they must be stiff and thermally stable. One concept for achieving these properties is the use of high modulus graphite epoxy, oriented in the longitudinal direction, overwrapped with thin aluminum foil. Use of the foil provides the potential for significant improvements over conventional graphite epoxy struts. The more important of these features are an improvement in thermal conductivity and the incorporation of a vapor barrier. Thermal gradients, which are a result of nonuniform heating will be reduced as the conductivity is increased. The use of an aluminum surface has been shown to almost completely control the absorption (or desorption) of moisture, if it is a problem.

Estimated properties have been determined for four types of longitudinal fiber/epoxy, overwrapped with aluminum foil. These properties are based on the data shown in Table 1, for a 60-percent fiber volume, and are presented in Figs. 1 through 4. The four types of graphite fiber are T-300, VSB-32(55 MSI), VSC-32(75 MSI), and VS-0054(100 MSI). The effect of a thin aluminum layer is readily evident. For example, the addition of a layer of 1 mil of aluminum on the surface of an 0.020-in. wall of P-75 (Fig. 3) GR/E results in a transverse thermal conductivity of approximately 3 Btu/hr-ft-°F, compared with 0.1 for bare GR/E. This is accomplished with almost no reduction in modulus of elasticity (43 versus 44 MSI). In this case, the coefficient of thermal expansion (CTE) is negative (-0.5 /°F). A zero CTE can be obtained using 100 MSI pitch fiber and 3.5 mils of aluminum, curve 3, Fig. 4. For this example, E is 47 MSI and K = 32 Btu/hr-ft-°F. The density of such a structure is 0.075 $lb/in.^3$

For cases where a slightly negative CTE is desired to compensate for positive CTE joints and fittings, it is possible to obtain higher values of E, and lighter weight structures.

Point (A), Fig. 4 represents a modulus of elasticity to density (E/ρ) value of approximately 10^9in. Although this point is for a bare (no aluminum) graphite epoxy tube, it should be easy to achieve the 10^9-in. value. A 65-percent fiber volume or a higher modulus fiber would make it possible to obtain this value with the aluminum foil wrap.

PROCESS RATIONALE

The struts were wound on the LMSC vertical winding machine using dry fiber. Two methods of introducing the resin were considered. One procedure incorporated a doctor blade for spreading the resin during the winding procedure as the carriage traverses from the bottom of the machine to the top. This procedure was used for manufacturing the parts which were wound with aluminum foil. A second approach was to use resin injection for the graphite parts without the aluminum foil wrap. This procedure was not developed during this study. A brief discussion of the rationale for selecting the mandrel, the vertical winding machine, and the fiber handling system is presented below.

Table 1

ESTIMATED PROPERTIES

GR/E = 60-Percent Fiber Volume

	T-300	P-55	P-75	P100	Al
E_L - MSI	20	34	44	60	10.5
E_T - MSI	1.5	0.9	0.9	0.9	10.5
	0.29	0.3	0.3	0.3	0.33
G_{LT} - MSI	0.66	0.6	0.60	0.6	3.97
CTE_L - 10^{-6}/°F	0.05	-0.28	-0.6	-0.79	13.0
CTE_T - 10^{-6}/°F	16.5	19.0	19.0	19.0	13.0
- lb/in.^{3}	0.057	0.58	0.063	0.067	0.10
k_{11} - Btu/hr-ft-°F	3.3	35	58	137	76
k_{22} - Btu/hr-ft-°F	0.1	0.1	0.1	0.1	76

GRAPHITE EPOXY STRUTS

ALUMINUM FOIL SKIN

GRAPHITE FIBER : T-300

LEGEND	$t_{GR/E}$ (in.)	AL SURFACE ONE SIDE	AL SURFACE BOTH SIDES
1	0.020	X	
2	0.040	X	
3	0.020		X
4	0.040		X

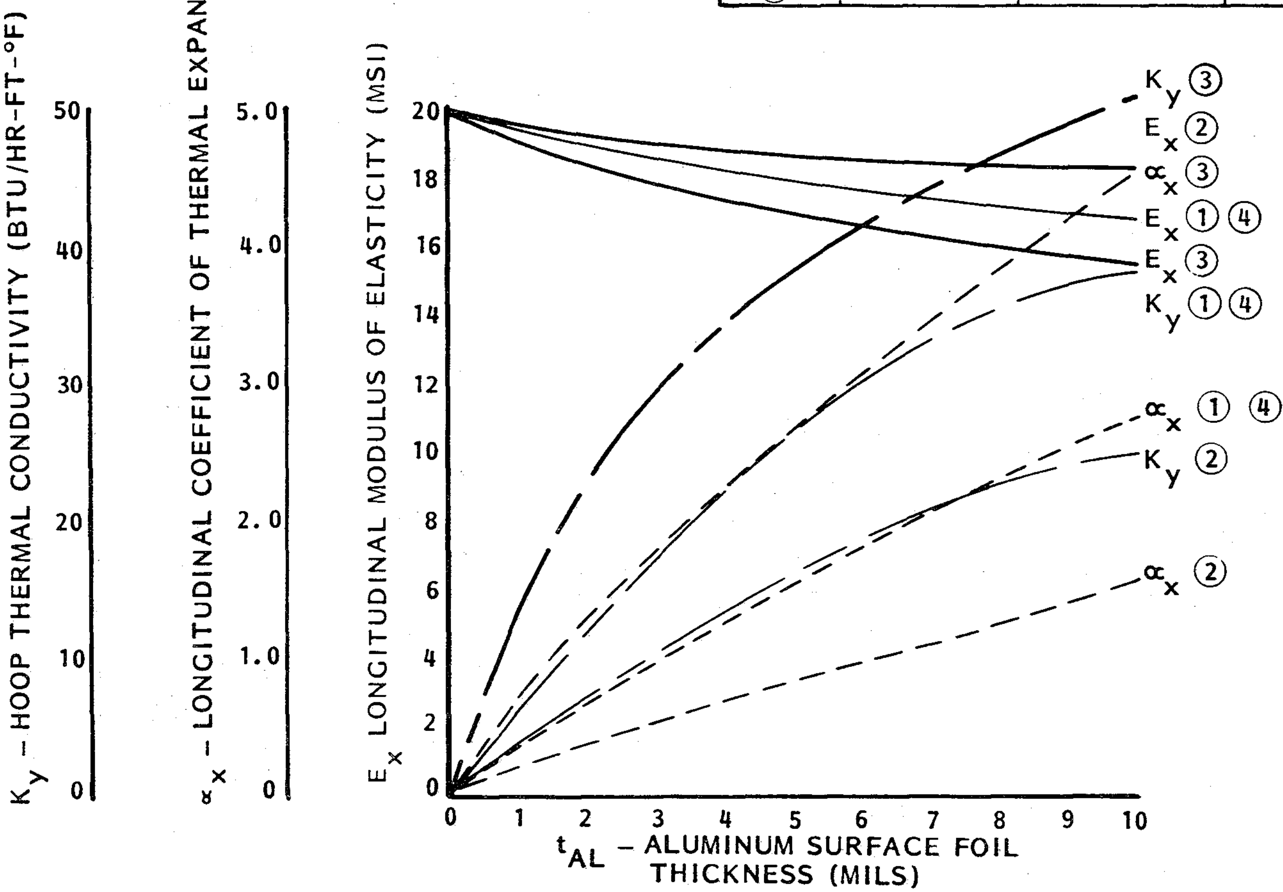


Fig. 1 Graphite Epoxy Struts, Aluminum Foil Skin-Graphite Fiber: T-300

GRAPHITE EPOXY STRUTS
ALUMINUM FOIL SKIN
GRAPHITE FIBER: 55 MSI PITCH

LEGEND	$t_{GR/E}$(in.)	AL SURFACE ONE SIDE	AL SURFACE BOTH SIDES
①	0.020	X	
②	0.040	X	
③	0.020		X
④	0.040		X

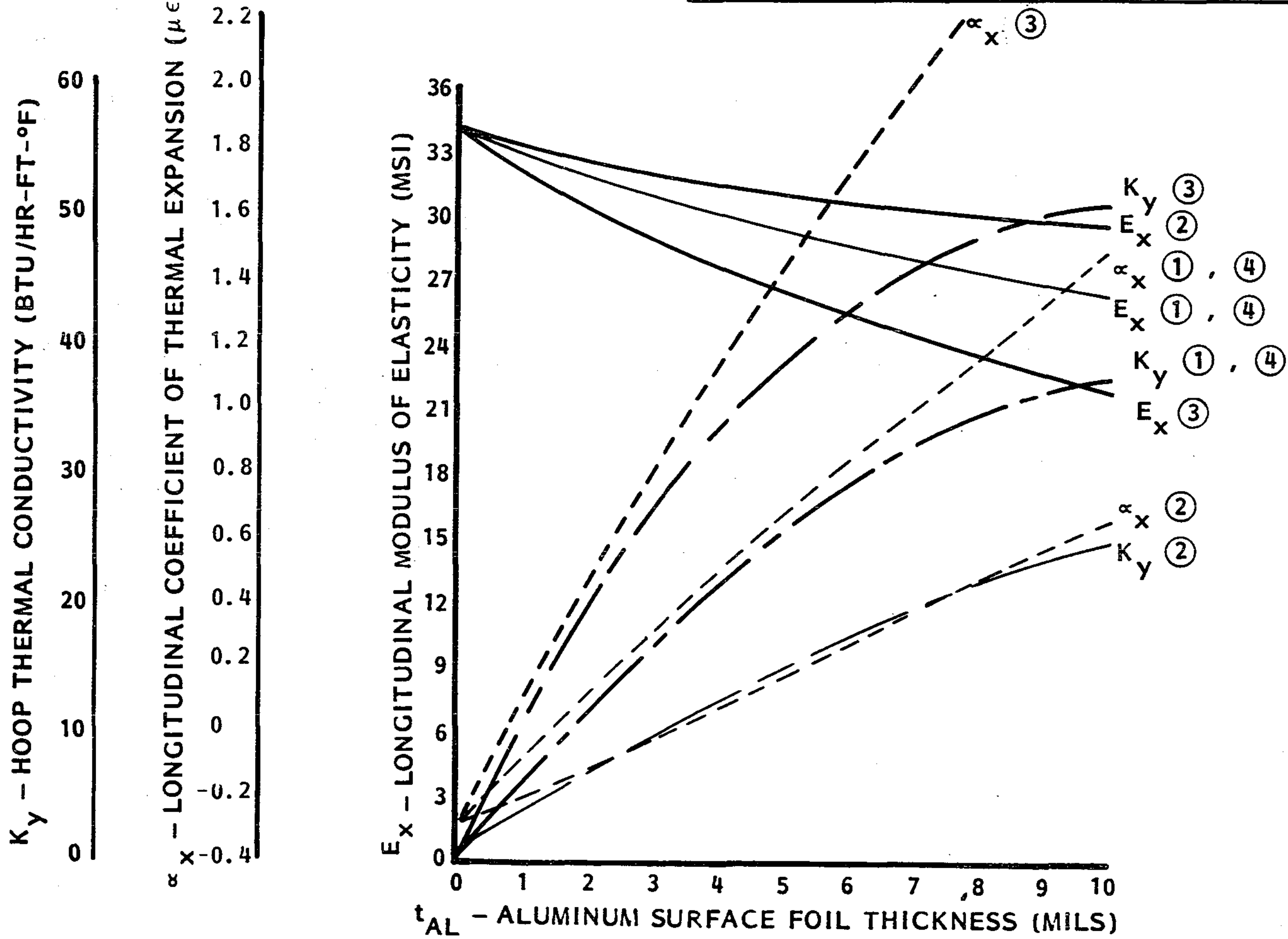
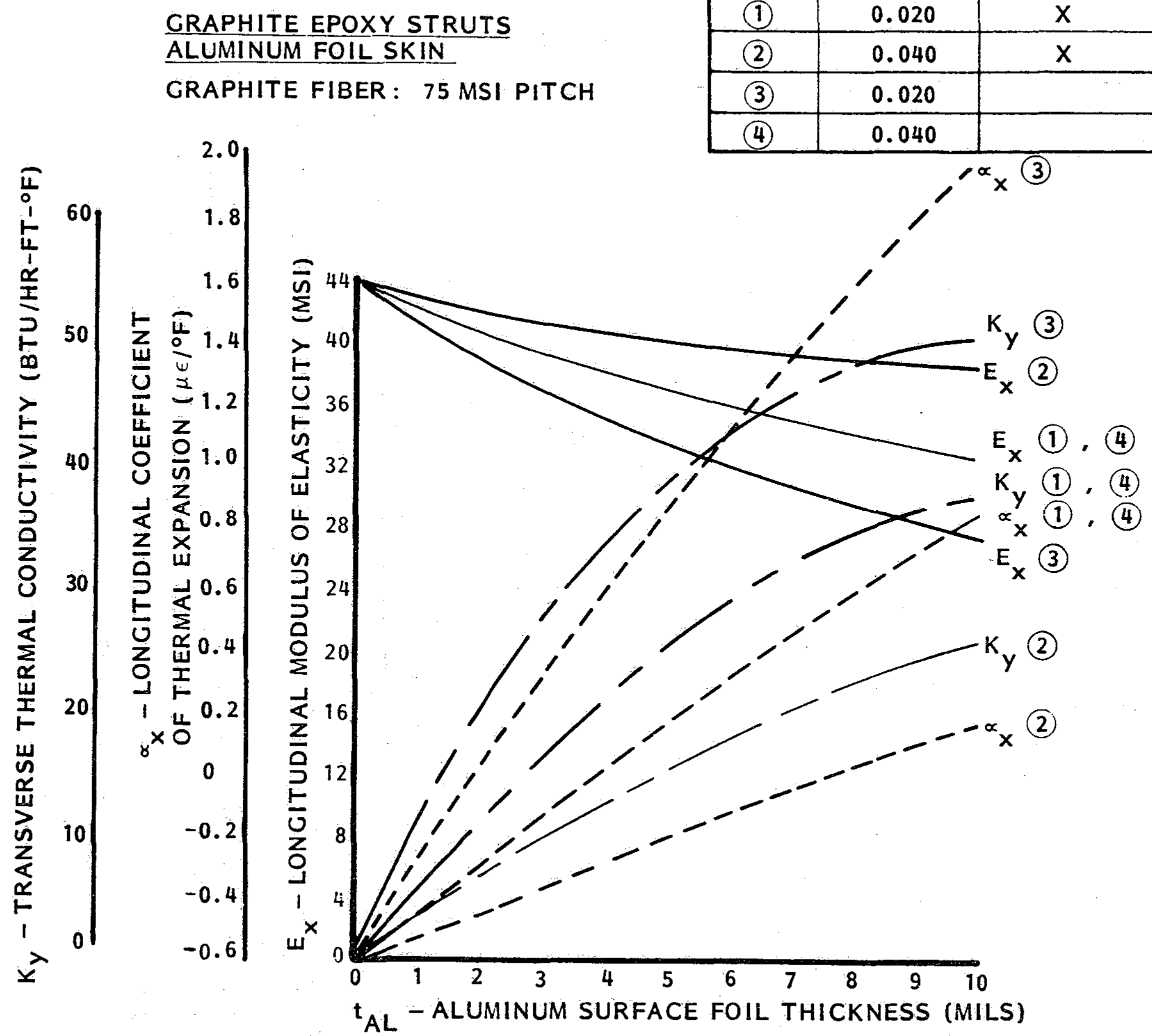


Fig. 2 Graphite Epoxy Struts, Aluminum Foil Skin-Graphite Fiber: 55 MSI Pitch



LEGEND	$t_{GR/E}$ (in.)	AL SURFACE ONE SIDE	AL SURFACE BOTH SIDES
①	0.020	X	
②	0.040	X	
③	0.020		X
④	0.040		X

Fig. 3 Graphite Epoxy Struts, Aluminum Foil Skin-Graphite Fiber: 75 MSI Pitch

GRAPHITE EPOXY STRUTS

ALUMINUM FOIL SKIN

GRAPHITE FIBER: 100 MSI PITCH

LEGEND	$t_{GR/E}$(in.)	AL SURFACE ONE SIDE	AL SURFACE BOTH SIDES
①	0.020	X	
②	0.040	X	
③	0.020		X
④	0.040		X

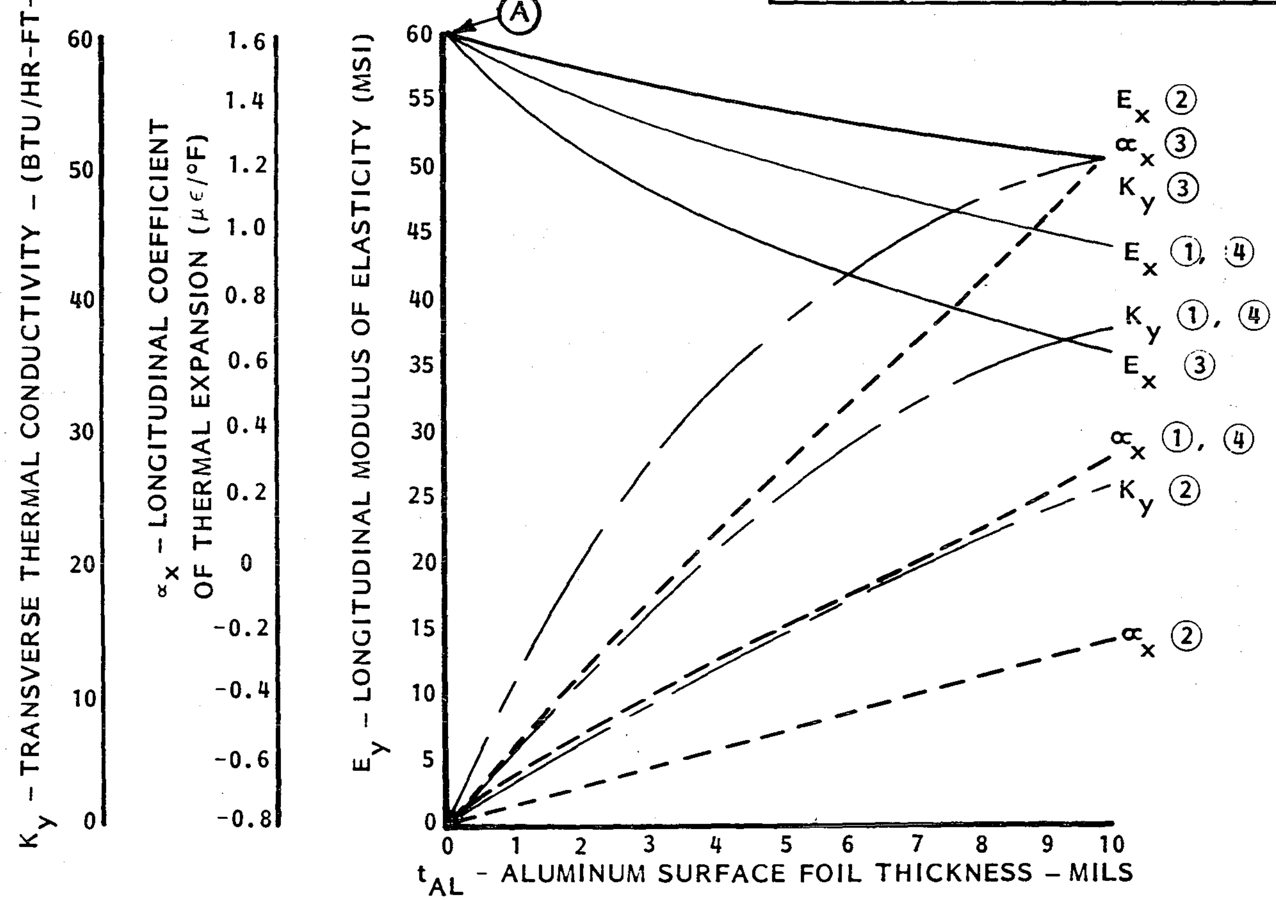


Fig. 4 Graphite Epoxy Struts, Aluminum Foil Skin-Graphite Fiber: 100 MSI Pitch

A solid teflon rod was used for the mandrel to provide compaction, because of its large coefficient of thermal expansion (CTE) during the cure process. The teflon rod also provides an easy technique for the removal of the mandrel from the finished part. The diameter of the teflon rod is reduced by applying a tension load to the rod, and the part is easily removed.

The LMSC vertical winding machine was used because it provides the most expeditious means to introduce longitudinal filament, and avoids mandrel sag during winding. The use of a nonrotating mandrel precludes the potential of mandrel whip.

A significant reduction in the labor intensive operation of loading the fiber was achieved by using a Leesona winder to spool the fibers. The fibers were then mounted on a creel. This procedure made it possible to wind a large number of parts with only one loading of fiber.

MANUFACTURING PROCESS

The key elements of the manufacturing process include:

- Respool the fiber using the Leesona winder. Up to 1600 ft of single tow can be wound on one spool.
- Install the 10-ft long 1/2-in diam teflon mandrel.
- Install the spooled fiber on the creel and thread the fiber through the ceramic eyelets in the fiber alignment plate.
- Install 0.001-in. thick aluminum foil on the canted stock spools. These axes are canted to accommodate the aluminum foil overwind.
- Load resin into resin container (Fiber Resin (FR) 8701). During winding, the resin is fed to a doctor blade for mandrel coating.

- The resin, longitudinal fiber, and aluminum foil overwrap are applied in one pass to the mandrel as the carriage traverses upward.

The wound part is then inserted into a steam-heated, 3-in. diam tubular oven for curing. After the part is cured, the tube is slipped off the mandrel by applying mandrel tension, thus reducing the mandrel diameter. The tube is cured on the mandrel at 250°F for 1 h and then at 335°F for 1 h.

A photograph of the overall setup of the winding operation is shown in Fig. 5. A carriage is shown on which are mounted the creel of fiber spools, a plate containing ceramic eyelets through which the fiber is fed, and a gear-driven ring to which the aluminum foil spools are attached. Also visible in the picture is the vertically mounted 1/2-in. diam mandrel. The length below the aluminum spools has been wrapped with foil which captures the fiber as it is wound on the mandrel. Figure 6 is a photograph showing in detail the fiber being fed through the alignment plate. The spools of aluminum foil, and the ring to which they are attached, are shown in Fig. 7. Completed tubes are shown in Fig. 8.

Tubes with other fiber configurations were made using this procedure. Specifically, a ±10-deg graphite fiber tube with an aluminum overwrap was manufactured. In this case, two passes were required. First, the +10-deg wrap was put on, and then the -10-deg wrap and the aluminum foil. A simple modification is required to the graphite fiber creel mounting. In laying down unidirectional fiber with the aluminum overwrap, the spools of aluminum foil are mounted on the rotating ring and the fiber creel is mounted on the nonrotating frame. For the ±10-deg configuration, the fiber creel is attached to the rotating ring which makes it possible to wrap the fiber around the mandrel.

The aluminum foil used is 1100 full hard (30 ksi UTS), 1/2-in. wide, and was selected because it was readily available.

The amount of fiber in each part is precisely known, since a fixed number of tows (spools) are fed through the ceramic eyelets.

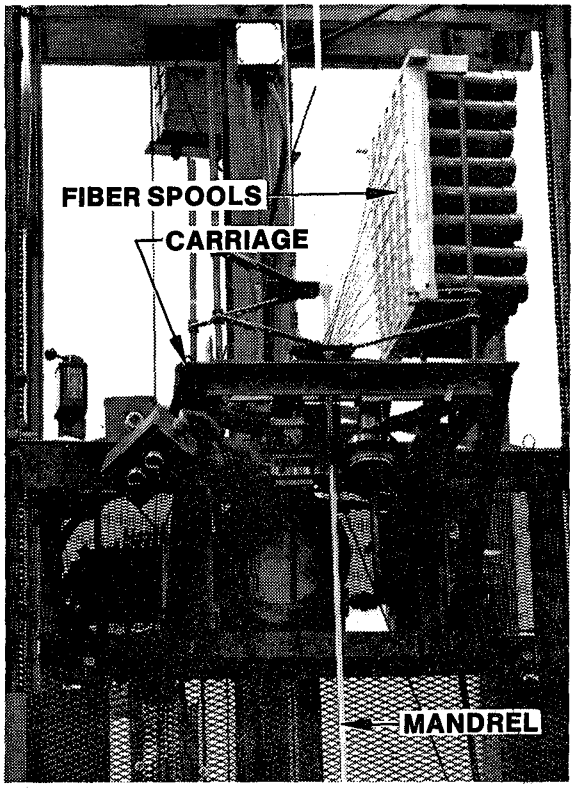


Fig 5 Overall Winding Setup

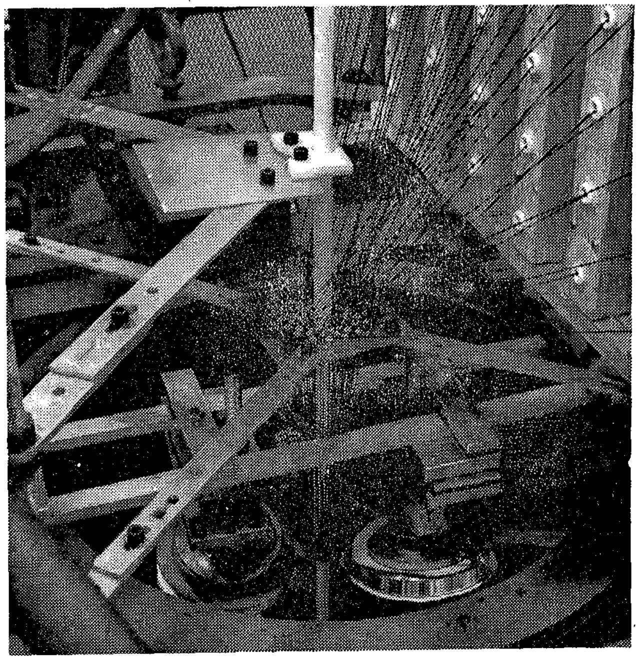


Fig 6 Closeup From Top

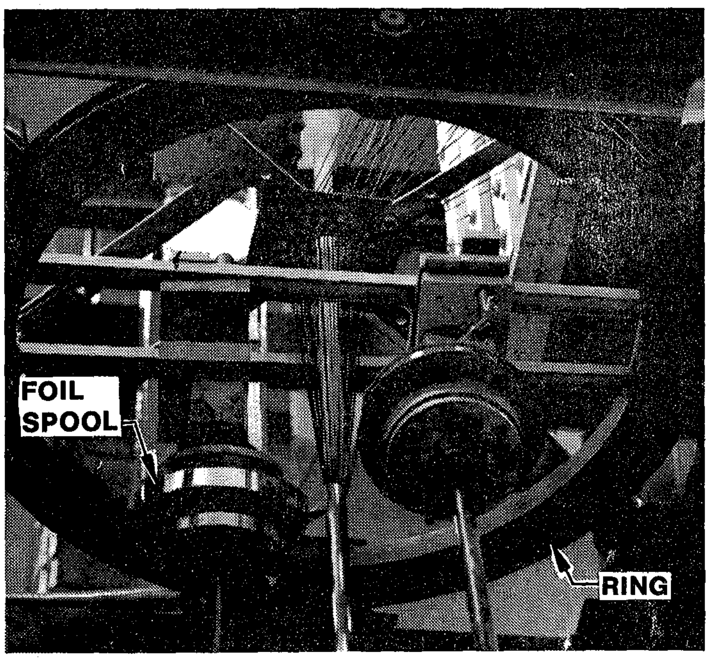


Fig. 7 Looking Upward


Fig 8 Fabricated Tubes

VERIFICATION REQUIREMENTS

The objective of this task was to develop a manufacturing process and demonstrate its feasibility. In this process of making the tubes, a number of manufacturing elements has been demonstrated.

- o Ability to wind aluminum fiber with good adhesion
- o Use of creeled fiber in the winding process
- o Development of a single-pass operation
- o Ease of removing mandrel
- o Ability to make slender straight tubing

Also, a tube was made with an aluminum foil inside and out by winding the first foil wrap on the mandrel.

Although the manufacturing feasibility has been demonstrated, more complete control of the properties can be achieved by using hard tooling on the outside, and injecting resin instead of the current technique of spreading the resin by blade.

More important, however, is the need for verification of the physical properties and manufacturing parameters.

In addition to a verification of the properties presented in Figs. 1 through 4, a fiber volume and void evaluation are required. The performance of the foil in the thermal cycling environment of space needs to be evaluated. The efficiency of the foil as a vapor barrier could be of considerable importance in some applications. Quantitative data are needed to evaluate the validity of the manufacturing process.

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Final Report

16. Abstract

A procedure for manufacturing long slender graphite tubing is desired. Such tubing has considerable application in truss supported spacecraft applications. The motivation for the selection of the tubing size developed in this program is for use as struts in a NASA, Langley Research Center truss supported antenna concept. The manufacturing procedure uses the LMSC vertical winding machine. A procedure for fabricating graphite epoxy tubing with an aluminum foil inner and outer wrap was also developed. The aluminum foil provides a vapor barrier, significantly improves the thermal conductivity, and provides an excellent thermal control surface.

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